APPENDIX C

CALCULATION OF A "SQUARE WAVE" FOR THE GROUNDWATER PATHWAY

Potential human exposure and risk through the groundwater pathway are estimated for both land application and surface disposal of sewage sludge. To prepare input for the VADOFT model of pollutant transport through the unsaturated zone, it is conservatively assumed for both land application and surface disposal that the pollutant is consistently loaded into the top of the unsaturated zone at the maximum rate estimated by mass balance calculations. The duration of this constant pulse, or "square wave", is constrained so that the total mass of pollutant leaching or seeping from the site is conserved. Although the general approach is the same for both land application and surface disposal, details differ according to which management practice is being considered. This appendix provides a brief discussion of the methods for estimating the magnitude and duration of the "square wave" of pollutant loading for land application and both prototype facilities for surface disposal.

Land Application

Both inorganic and organic pollutants can accumulate in soil with repeated applications of sewage sludge. As described in Chapter 4, it is assumed that all competing pollutant loss processes for sewage sludge-amended soil can be approximated as first-order, and that coefficients describing the rate of loss to each process can be summed to yield a total or "lumped" coefficient for first-order loss. Losses at any time t can then be described as:

$$\frac{dM_t}{dt} = -K_{tot} M_t$$

where:

M_t = mass of pollutant in sewage sludge-amended soil at time t (kg) and
K_{tot} = total loss rate for the pollutant from sewage sludge-amended soil (yr^{-1}).

If pollutant loading to treated soil is approximated as a continuous process, the mass of pollutant in soil after t years of applications can be described by:

$$M_t = \int_0^t PA\ e^{-K_{tot}x}\ dx = \frac{PA}{K_{tot}} (1 - e^{-K_{tot}t})$$

where:

PA = total annual loading of pollutant to site (kg/yr).

As t approaches infinity, M_t therefore approaches $(PA)/K_{tot}$ and yearly loss approaches yearly loading.

For organic pollutants, it is assumed that sewage sludge has been applied repeatedly until steady-state is achieved. In other words, pollutant has accumulated in the soil until total yearly losses through erosion, degradation, leaching, and volatilization (which are assumed to be proportional to the concentration in soil) catch up with yearly loadings of pollutant to

soil. Estimates of risks from organic pollutants on land application sites are derived for this steady-state condition. The amplitude of the square wave pulse for the groundwater pathway model is therefore equal to the annual loading of pollutant multiplied by the fraction of annual loss attributable to leaching. The length of the square wave is equal to the length of the simulation (300 years).

For inorganic pollutants, this condition of steady-state is not necessarily reached. The leaching of inorganic pollutants from sewage sludge to groundwater depends not only on the cumulative loading of inorganic pollutants, but also on the period of time in which this cumulative loading takes place. It is assumed that after 20 years, applications are discontinued. To capture the risks associated with the peak rate at which inorganic pollutants leave the soil layer, the peak loss rate (calculated for the 20th year of application) is used for the calculations. The length of the square wave is calculated by dividing the total (cumulative) loading of pollutant by this maximum rate of loss:

$$TP = \frac{N\ PA}{PA\ (1-e^{-K_{tot}t})} = \frac{N}{(1-e^{-K_{tot}N})}$$

where:

TP = duration of "square wave" for approximating the loading of pollutant into the unsaturated soil zone (yr).

Surface Disposal: Monofill Prototype

The modeling of the groundwater pathway for the monofill prototype of surface disposal is similar to that for land application. For both cases, it is assumed that the site receives repeated loadings of pollutant for the duration of its active lifetime. By analogy with the above discussion for land application, this maximum rate of loss from the facility can be described as a function of its yearly loading, yearly loss, and number of years of active operation:

$$K_{tot}\ M_{LF} = PA\ (1-e^{-K_{tot}\ LF})$$

where:

LF = active lifetime of monofill (yr),

M_{LF} = mass of pollutant in sewage sludge/soil at end of monofill's active lifetime (kg), and

PA = total annual loading of pollutant to monofill (kg/yr).

The length of time this maximum rate of loss could be maintained is then:

$$TP = \frac{LF\ PA}{PA\ (1-e^{-K_{tot}\ LF})} = \frac{LF}{1-e^{-K_{tot}\ LF}}$$

Surface Disposal: Surface Impoundment Prototype

For the surface impoundment prototype of surface disposal, calculations are based on the conservative assumption that steady-state is maintained for concentrations of pollutants within the liquid and sediment layers of the impoundment. It is also assumed that the flux of pollutant leaching from the impoundment is constant with respect to time, at least until the total mass of pollutant deposited in the impoundment has been depleted. For this prototype, the length of the square wave used for execution of the VADOFT model is therefore equal to the total mass of pollutant entering the impoundment each year, multiplied by the expected lifetime of the facility and divided by the amount lost each year:

$$TP = \frac{PA \cdot TF}{31{,}536{,}000 \cdot PA \cdot f_{act}} = \frac{TF}{31{,}536{,}000 \cdot f_{act}}$$

where:

PA	=	total annual loading of pollutant into the surface impoundment (kg/yr),
TF	=	estimated active lifetime of surface impoundment (sec),
31,536,000	=	constant to convert (sec) to (yr), and
f_{act}	=	fraction of each year's loading of pollutant lost during each year of the surface impoundment's active phase (dimensionless).

APPENDIX D

EVALUATION OF CANDIDATE POLLUTANTS FOR THE ROUND TWO SEWAGE SLUDGE REGULATION

EVALUATION OF CANDIDATE POLLUTANTS FOR THE ROUND TWO SEWAGE SLUDGE REGULATION

by

U.S. ENVIRONMENTAL PROTECTION AGENCY
401 M STREET, S.W.
WASHINGTON, D.C. 20460

AUGUST 1996

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1. INTRODUCTION

1.1 BACKGROUND

In 1987, Congress amended section 405 of the Clean Water Act (CWA) to require a comprehensive program to reduce the potential public health and environmental risks from the use or disposal of sewage sludge, which is solid, semi-solid, or liquid residue generated during the treatment of domestic sewage in a treatment works. Amended section 405(d) established a timetable for the development of the sewage sludge use or disposal regulations. The basis for the program Congress mandated to protect public health and the environment is the development of technical requirements or standards for sewage sludge use or disposal, and the implementation of the standards through a permit program.

Under the current section 405(d), EPA first had to identify toxic pollutants that may be present in sewage sludge in concentrations that may affect public health and the environment. Next, for each identified use or disposal practice, EPA had to publish regulations that specify management practices for sewage sludge that contains the toxic pollutants and establish numerical limits for the toxic pollutants. The management practices and numerical limits must be "adequate to protect public health and the environment from any reasonably anticipated adverse effect of each pollutant." Section 405(d) requires that EPA publish the sewage sludge regulations in two rounds and then review the regulations periodically to identify additional pollutants for regulation.

On February 19, 1993, EPA published the Round One sewage sludge regulation (i.e., the Standards for the Use or Disposal of Sewage Sludge - 40 CFR Part 503) in the *Federal Register* (58 *FR* 9248). It was amended subsequently on February 24, 1994 (59 *FR* 9095), and on October 25, 1995 (60 *FR* 54764).

A candidate list of pollutants for the second round of the sewage sludge regulations (i.e., Round Two) was provided to the District Court in Oregon in May 1993 (see Appendix D1). The final list of pollutants was submitted to the District Court in Oregon in November 1995 (see Appendix D2). The Round Two sewage sludge regulation is scheduled for proposal in December 1999 and for publication in December 2001.

To develop the final list of pollutants for the Round Two sewage sludge regulation, a Comprehensive Hazard Identification study was conducted by use or disposal practice for the 31 pollutants on the candidate list. Results of that study were used to determine the candidate pollutants that warrant further consideration for the Round Two list of pollutants.

1.2 PURPOSE

This paper reviews the candidate pollutants from the Comprehensive Hazard Identification study that warrant further consideration for the Round Two list of pollutants and presents the rationales for not including some of the pollutants on the final list. It also presents the pollutants on the final list of pollutants for the Round Two sewage sludge regulation.

1.3 POLICY DECISIONS

For the review of the candidate pollutants from the Comprehensive Hazard Identification study that warrant further consideration for the Round Two list, EPA made several policy decisions. They are:

- Uptake rates from non-sewage sludge studies (i.e., crops for which the uptake rates were obtained were not grown in sewage sludge-amended soil) are not appropriate for crops grown in sewage sludge-amended soils because sewage sludge is expected to "bind" pollutants and makes them less available for plant uptake

(Corey et al., 1987).

- Potential population effects are of greater concern than are individual effects for exposure pathways in which the Highly Exposed Individual (HEI) is a nonendangered animal.

- The route through which a pollutant is administered (e.g., in drinking water or food) in a toxicity study should be considered when determining the applicability of the study to an exposure pathway.

- A soil type for all land application sites and surface disposal sites of either sandy loam, shrinking clay, or sand is reasonable.

- A margin of safety that is smaller than the total uncertainty factor used for the Reference Dose (RfD) is reasonable in certain cases.

1.4 ADDITIONAL INFORMATION

Questions about the information in this paper should be addressed to:

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2. POLLUTANT EVALUATIONS

2.1 CANDIDATE POLLUTANTS THAT WARRANT CONSIDERATION

During the Comprehensive Hazard Identification study (U.S. EPA, 1996), 15 exposure pathways were evaluated for land-applied sewage sludge and two pathways were evaluated for sewage sludge placed on a surface disposal site. A pathway was considered "critical" for a pollutant if the risk level for a carcinogenic pollutant was 10^{-4} or higher; the ratio of exposure for a noncarcinogenic pollutant to its Reference Dose (RfD) was equal to or greater than one; or the risk quotient (RQ) for a pollutant for the ecological pathways was equal to or greater than one.

Based on the results of the Comprehensive Hazard Identification study, several of the candidate pollutants had critical pathways for land application and for surface disposal. The candidate pollutants and their critical pathways are presented in Table 2.1 for land application and Table 2.2 for surface disposal. The exposure pathway for incineration (i.e., inhalation) was not critical for any of the candidate inorganic pollutants. That pathway was not evaluated for the organic pollutants because organic pollutants are controlled by the allowable concentration of total hydrocarbons in the exit gas from a sewage sludge incinerator in the Part 503 regulation.

As indicated on Tables 2.1 and 2.2, dioxins, dibenzofurans, and coplanar polychlorinated biphenyls (PCBs) have several critical pathways. For this reason and because dioxins, dibenzofurans, and coplanar PCBs are bioaccumulative pollutants (i.e., they accumulate in human and animal tissues) with reproductive effects, EPA concluded that those pollutants should be on the final Round Two list of pollutants for land application and surface disposal.

TABLE 2.1 - POLLUTANTS WITH CRITICAL LAND APPLICATION PATHWAYS

Pollutant	Critical Ag Pathway	Critical Non-Ag Pathway
Aluminum	6	6(f,r,p)
Antimony	7,14	7(f,r); 10(f,p); 14(f,r,p,)
Barium	7,10,14	7(f,r); 10(f,r,p); 14(f,r,p)
Beryllium	14	14(f,r,p)
Boron		6(f,p)
Dioxins/furans	2,3,10,12,13,15	3(f,r,p); 10(f,r,p); 12(f,r,p); 13(f,r,p); 15(f,r,p)
Fluoride	6,10	6(f,r,p); 10(f,r,p)
Manganese	3,6,7,14	3(f,r,p); 4(f,r); 6(f,r,p); 7(f,r); 10(f,p); 14(f,r,p)
PCBs - coplanar	3,4,5,6,15	3(f,r,p); 4(f,r); 5(f,r); 6(f,r,p); 13(f,r); 15(f,r,p)
Thallium	3	3(f,r,p)
Tin	7	7(f,r)
Titanium	6	6(r)

Pathway 2 - residential home gardener
Pathway 3 - child ingesting sewage sludge
Pathway 4 - human ingesting animal products (foraging animals)
Pathway 5 - human ingesting animal products (grazing animals)
Pathway 6 - livestock ingesting forage/pasture
Pathway 7 - livestock ingesting sewage sludge
Pathway 10 - soil organism predators ingesting soil organisms
Pathway 12 - humans ingesting surface water and fish
Pathway 13 - humans inhaling volatilized pollutants
Pathway 14 - humans ingesting groundwater
Pathway 15 - breast-feeding infant
f - forest; r - reclamation site; p - public contact site; ag - agricultural land; non-ag - non-agricultural land

TABLE 2.2 - POLLUTANTS WITH CRITICAL SURFACE DISPOSAL PATHWAYS

Pollutants	Monofills	Surface Impoundments
Antimony	-	Ground water
Barium	-	Ground water
Beryllium	-	Ground water
Dioxins/furans	-	Air
Manganese	-	Ground water

EPA also concluded that the inorganic pollutants with critical pathways for land application and surface disposal should not be on the final list of pollutants for the Round Two regulation. The rationales for excluding those pollutants from the list are presented below.

2.2 INFORMATION USED TO DEVELOP RATIONALES TO EXCLUDE INORGANIC POLLUTANTS FROM FURTHER CONSIDERATION

The Comprehensive Hazard Identification study used to evaluate the candidate inorganic pollutants was, by design, conservative. After the critical pathways were identified for each pollutant, a detailed examination of each pathway was conducted by EPA to confirm that the pathway results supported inclusion of the pollutant on the final Round Two list of pollutants.

As part of the detailed examination for each critical pathway for a pollutant, three reviews were conducted. First, the assumptions made in conducting the pathway exposure assessment were reviewed. Next, the relevance of available toxicity data for a pathway to the Highly Exposed Individual (HEI) for the pathway was reviewed. Finally, the magnitude of the ratio of estimated exposure to the RfD for a noncarcinogenic pollutant in the non-ecological pathways or

the magnitude of the ratio of the estimated exposure to the toxicological reference value (TRV) for a pollutant in the ecological pathways was reviewed.

2.2.1 Land Application

The information in Tables 2.3, 2.4, 2.5, and 2.6 was used in the detailed examination of the critical land application pathways. Table 2.3 contains a summary of conservative assumptions for several of the critical pathways. Table 2.4 contains the Highly Exposed Individual (HEI) for each of the critical pathways, and Table 2.5 contains the measurement endpoint for each pollutant by critical pathway and the species used to develop the endpoint. Table 2.6 contains the results of the Comprehensive Hazard Identification study for each of the critical pathways.

TABLE 2.3 - SUMMARY OF CONSERVATIVE ASSUMPTIONS

Pathway	Conservative Assumption
3	One hundred percent of the material that the child ingests is sewage sludge, not a mixture of soil and sewage sludge.
4	Results from non-sewage-sludge studies can be used to develop pollutant uptake slopes into forage/pasture.
6	Herbivorous livestock or small herbivorous animals forage only on land on which sewage sludge has been applied; results from non-sewage-sludge studies can be used to develop pollutant uptake slopes into forage/pasture.
7	Herbivorous livestock graze only on land on which sewage sludge has been applied.
10	All of the soil organisms ingested by small mammals are exposed to sewage sludge-amended soil and, therefore, bioconcentrate pollutants.
14	The soil-water partition coefficient used is the lowest soil-water partition coefficient for sandy soil with a porewater pH of 5.

TABLE 2.4 - HIGHLY EXPOSED INDIVIDUALS FOR CRITICAL PATHWAYS

Pathway Number	Highly Exposed Individual (HEI)
3-agricultural	Child ingesting sewage sludge
3-non-agricultural	Child ingesting sewage sludge
4-non-agricultural	Human ingesting deer and elk
6-agricultural	Herbivorous livestock
6-non-agricultural	Herbivorous livestock (forest, reclamation site); small herbivorous mammal (forest, public contact site)
7-agricultural	Herbivorous livestock
7-non-agricultural	Herbivorous livestock
10-agricultural	Small insectivorous mammal ingesting soil organisms
10-non-agricultural	Small insectivorous mammal ingesting soil organisms
14-agricultural	Human ingesting ground water
14-non-agricultural	Human ingesting ground water

TABLE 2.5 - MEASUREMENT ENDPOINTS FOR CRITICAL PATHWAYS

Pollutant	Pathway Number	Endpoint/Species[1]
Aluminum	6	TRV/rat
Antimony	7 10 14	TRV/rat TRV/rat RfD/rat
Barium	7 10 14	TRV/rat TRV/rat RfD/human
Beryllium	3 14	CRL CRL
Boron	6	TRV/dog
Fluoride	6 10	TRV/mice TRV/mice
Manganese	3 4 6 7 10 14	RfD/human RfD/human TRV/rat TRV/rat TRV/rat RfD/human
Thallium	3	RfD/rat
Tin	7	TRV/rat
Titanium	6	TRV/mice

[1] CRL - cancer risk level
RfD - risk reference dose
TRV - toxicological reference value

TABLE 2.6 - RESULTS OF RISK ASSESSMENT FOR CRITICAL PATHWAYS

Pollutant	Pathway Number	RfD Ratio[1]	RQ[2]
Aluminum	6(ag,f,r,p)	-	80(f,p), 100(ag,r)
Antimony	7(ag,f,r) 10(f,p) 14(ag,f,r,p)	- - 20(ag),40(f),3(r),60(p)	1(ag,f,r) 3(f,p) -
Barium	7(ag,f,r) 10(ag,f,r,p) 14(ag,f,r,p)	- - 9(ag),20(f),1(r), 20(p)	40(ag,f,r) 10(ag,r), 50(f,p) -
Beryllium[1]	14(ag,f,r,p)	$7x10^{-4}$(ag),$9x10^{-4}$(f) $3x10^{-4}$(r),$1x10^{-3}$(p)	-
Boron	6(f,p)	-	4(f,p)
Fluoride	6(ag,f,r,p) 10(ag,f,r,p)	- -	10(ag,r),30(f,p) 5(ag,r),8(f,p)
Manganese	3(ag,f,r,p) 4(f,r) 6(ag,f,r,p) 7(ag,f,r) 10(f,p) 14(ag,f,r,p)	4(ag,p),3(f,r) 10(f), 40(r) - - - 700(ag),1000(f), 30(r),2000(p)	- 200(ag,r),800(f,p) 1(ag,f,r) 2(f,p) -
Thallium	3(ag,f,r,p)	2(ag,p),1(f,r)	-
Tin	7(ag,f,r)	-	2(ag,f,r)
Titanium	6(ag,r)	-	7(ag,r)

[1]Ratio of estimated exposure to Reference Dose (RfD). For beryllium, the value is a carcinogenic risk level.
[2]Risk Quotient - ratio of estimated exposure to Toxicological Reference Value (TRV).

ag - agricultural land; f - forest land; r - reclamation site; p - public contact site

2.2.2 Surface Disposal

During the Comprehensive Hazard Identification study for surface disposal, soil-water partition coefficients for sand with a porewater pH of 5 were used for the ground-water pathway. This is the same conservative assumption that was used in the groundwater pathway analyses for land application.

Results of the Comprehensive Hazard Identification study for the critical surface disposal pathways are presented in Table 2.7.

TABLE 2.7 - RESULTS FOR CRITICAL SURFACE DISPOSAL PATHWAYS

Pollutant	Pathway	Cancer Risk Level	RfD Ratio[1]
Antimony	Ground water	-	4
Barium	Ground water	-	1
Beryllium	Ground water	2×10^{-4}	-
Manganese	Ground water	-	90

[1] Ratio of estimated exposure to the Reference Dose (RfD).

2.3 RATIONALES FOR EXCLUDING INORGANIC POLLUTANTS FROM FURTHER CONSIDERATION

The rationales for excluding inorganic pollutants from the list of pollutants for the Round Two sewage sludge regulation for land application and surface disposal are presented below.

2.3.1 Land Application

Aluminum

The critical pathway for aluminum for land application is Pathway 6 (animal foraging) for both agricultural land and non-agricultural land (forest, reclamation sites, and public contact sites). As indicated in Table 2.3, the uptake slopes used in the Pathway 6 analyses were obtained from non-sewage sludge studies (i.e., crops from which the uptake slopes were obtained were not grown in sewage sludge-amended soil). EPA concluded it is not appropriate to use those uptake slopes to estimate the uptake of aluminum into forage grown in sewage sludge-amended soils (see Policy Decision on page 2). No other information was available on uptake slopes for aluminum.

Because aluminum is not a bioaccumulative pollutant (i.e., does not accumulate in human or animal tissue); because Pathway 6 was the only critical pathway for aluminum from the Comprehensive Hazard Identification study; and because after the detailed review of Pathway 6, it could not be evaluated using available information, EPA concluded that aluminum should not be on the list of pollutants for the Round Two regulation for land application.

Antimony

One of the critical pathways for antimony for land application is Pathway 7 (grazing animal that ingests sewage sludge directly). As indicated in Tables 2.3 and 2.5, the measurement endpoint (i.e., the toxicological reference value (TRV)) for this pathway for both agricultural and non-agricultural land is based on results of studies using laboratory animals (i.e., rats). This endpoint was extrapolated to the appropriate HEI (i.e., herbivorous animals) for the land application risk assessments.

The lowest observed adverse effect level (LOAEL) for antimony is 0.262 mg/kg-body weight/day, which is based on the results of a study in which antimony was fed to rats in water (Schroeder et al., 1970). This value was converted to a dietary value (i.e., 3.4 mg/kg-food) using a standard body weight of 0.4 kilograms for a rat and allometric equations (U.S. EPA, 1988). A decrease in survival and longevity for male and female rats was observed at this dose equivalent. The dietary value was divided by 10 to obtain the TRV for antimony.

There are two reasons why it is not appropriate to use the TRV for laboratory animals as the TRV for the HEI in the Pathway 7 exposure analyses for agricultural land, forests and reclamation sites. First, the study on which the LOAEL for antimony was based (Schroeder, 1970) indicates that the effect from exposure to antimony (a decrease in survival and longevity) occurs later in the life of a rat and growth was not affected. Thus, the potential for antimony to interfere with growth and reproduction (i.e., population effects) is unclear. Also, results of another study (Schroeder et al., 1968a) indicate a decrease in survival and longevity due to exposure to antimony was not observed in mice.

Second, the LOAEL on which the TRV is based was obtained from a study in which antimony was fed to rats in water. Gastrointestinal absorption of antimony in food is expected to be lower than the gastrointestinal absorption of antimony in drinking water. For example, results of other rat studies (Sunagawa, 1981; Smyth and Thompson, 1945) in which antimony was administered in food indicate that the no observed adverse effect level (NOAEL) for antimony can be as high as 200 mg/kg-day and not cause specific systemic effects (e.g., changes in blood pressure). This value, which did not result in population effects, is over two orders of magnitude higher than the LOAEL used to develop the TRV for antimony.

Because there is uncertainty in the animal studies about whether exposure to antimony causes population effects and because the LOAEL used to develop the TRV is based on the results of a study in which rats were fed antimony in water, EPA concluded that it is not appropriate to use the TRV in the Comprehensive Hazard Identification study in the Pathway 7 analyses. In those analyses, the HEI ingests sewage sludge while grazing on sewage sludge-amended soil. Other TRV values would likely be much higher based on other toxicity data. If the TRV is based on a NOAEL of 200 mg/kg-day (i.e., the NOAEL from rat studies in which rats were fed antimony in food), the risk quotient for the Pathway 7 analyses would be less than one. For these reasons, EPA concluded that antimony should not be on the Round Two list of pollutants based on exposure through Pathway 7.

Pathway 10 (predator of soil organism) also was critical for antimony for land application. EPA concluded that the TRV used in the Comprehensive Hazard Identification study is not appropriate for this pathway for the same reasons the TRV for Pathway 7 is not appropriate. Given that the RQ was 3 and that other TRV values would likely be much higher based on other toxicity data, EPA concluded antimony should not be included on the final Round Two list of pollutants for land application based on exposure through Pathway 10.

Pathway 14 (i.e., ground water) in the land application Comprehensive Hazard Identification study for agricultural land and non-agricultural land also was critical for antimony. One way to evaluate the RfD ratio for this pathway (i.e., the highest ratio is 60 for public contact sites) is to consider the uncertainty factor for the RfD with respect to the RfD ratio and the effect upon which the RfD is based.

The antimony RfD is based on an uncertainty factor of 1000 (IRIS, 1996). The highest

RfD ratio for this pathway is 60 for public contact sites. In this case, the margin of safety (that is, the ratio between the uncertainty factor and the RfD ratio) is approximately 17 (i.e., 1000/60). EPA concluded that a margin of safety of 17 is sufficiently protective for the HEI (i.e., human) in this case because the effect upon which the RfD is based (i.e., changes in cholesterol and glucose blood levels) is not severe and is likely reversible. EPA also concluded that the margins of safety for the other types of land application sites (i.e., 50 for agricultural land, 25 for forest, and 333 for reclamation sites) are protective for the HEIs for those types of land application sites.

The above information indicates that the critical pathways from the Comprehensive Hazard Identification study should not be used as the basis for including antimony on the list of pollutants for the Round Two sewage sludge regulation. For this reason, antimony was not included on the list for land application.

Barium

One of the critical pathways for barium for land application was Pathway 7 (grazing animal that ingests sewage sludge directly). The TRV for this pathway for agricultural land, forest, and reclamation sites is based on results of studies using laboratory animals (i.e., rats). This endpoint was extrapolated to the appropriate HEI (i.e., herbivorous animals) for the land application risk assessments.

Study results reported in the Agency for Toxic Substances and Disease Registry (ATSDR, 1992a) were used as the basis for the TRV for barium. In those studies (Perry et al., 1983, 1985, 1989), barium was fed to rats in drinking water. The NOAEL for barium was 0.056 mg/kg- body weight/day, which corresponds to a concentration in drinking water of 1 ppm. The dietary

equivalent is 0.7 mg/kg-food when the NOAEL is converted using allometric equations (U.S. EPA, 1988).

The RQ for barium for Pathway 7 was 40. Even if the LOAEL were used as the basis for the TRV, instead of the NOAEL, the RQ would be 4. This means that the estimated exposure for Pathway 7 could cause the LOAEL to be exceeded.

The effect for the LOAEL for barium is an increase in systolic blood pressure. This effect was not seen, however, until the eight month of a 16 month rat study. No other toxic effects were observed in the study, and growth was not impaired. The impact of slight increases in systolic blood pressure for cattle, other grazing animals, and small mammals is unclear, and population effects (i.e., growth, reproductive, and mortality) for those animals cannot be evaluated using the results of the rat study.

A 1975 study found reduced life span in male mice given 5 ppm barium in drinking water (Schroeder and Mitchener, 1975). The calculated LOAEL for this study was 0.95 mg/kg-body weight/day, which has a dietary equivalent of 4.8 mg/kg-food when converted using an allometric equation (U.S. EPA, 1988). During the study, longevity only was reduced slightly. Other studies in which cardiovascular and other systemic effects from exposure to barium were evaluated found NOAELs at an order of magnitude higher than in the NOAEL based on the results of the Perry et al. studies.

EPA concluded that it is not appropriate to use the above TRV as the TRV for the HEI in the Pathway 7 exposure analyses because the observed effects from exposure to barium, which is a non-bioaccumulative pollutant, were not population effects. In addition, the effects that were observed (i.e., increase in systolic blood pressure) occurred as a result of exposure to barium in

drinking water. The absorption of barium in drinking water is likely to be higher than absorption of barium in food or in sewage sludge. For these reasons, EPA concluded that barium should not be on the Round Two list of pollutants for land application based on exposure through Pathway 7.

Pathway 10 (predator of soil organism) also was critical for barium in the Comprehensive Hazard Identification study for agricultural land and non-agricultural land. EPA concluded that the TRV used in that study for Pathway 10 is not appropriate for the same reasons the TRV for Pathway 7 is not appropriate. Therefore, EPA concluded barium should not be on the Round Two list of pollutants based on exposure through Pathway 10.

Pathway 14 (i.e., ground water) also was critical for barium for agricultural and non-agricultural land application. Two conservative assumptions were made for this pathway in the Comprehensive Hazard Identification study. One was the type of soil at the land application sites and the other was the value for the soil-water partition coefficient (K_d).

The type of soil affects the ability of a pollutant to move vertically to an aquifer and laterally to a nearby well. Soil types in the unsaturated zone beneath a land application site in order of increasing pollution potential are: (1) nonshrinking clay, (2) clay loam, (3) silty loam, (4) loam, (5) sandy loam, (6) shrinking clay, (7) sand, (8) gravel, and (9) thin or absent soil (U.S. EPA, 1992). EPA concluded that it is reasonable to assume a soil type of either sandy loam, shrinking clay, or sand as the soil type for all land application sites. In the case of barium, the assumed soil type for the land application sites was sand.

The K_d value for sand with a porewater pH of 5 varies from 6 liters per kilogram to 174 liters per kilogram (Gerritse et al., 1982). In the Comprehensive Hazard Identification study,

Pathway 14 was critical for barium because the lower end of the K_d range (i.e., 6) was used to estimate exposure from barium. If the upper end of the K_d range (i.e., 174) is used, Pathway 14 is not critical (i.e., the RfD ratio is less than one) for barium.

EPA concluded that because there is an acceptable range of partition coefficients, it is appropriate to use the upper end of the range, particularly when the soil type for all land application sites is assumed to be sand. Because Pathway 14 is not critical when the upper end of the partition coefficient range is used, EPA concluded that barium should not be on the Round Two list of pollutants for land application based on exposure through Pathway 14.

The above information indicates that after the detailed examination of the critical pathways for barium (i.e., 7, 10, and 14) in the Comprehensive Hazard Identification study, none of the pathways are critical for both agricultural land and non-agricultural land. For this reason, barium was not included on the final list of pollutants for the Round Two regulation for land application.

Beryllium

Pathway 14 was critical for beryllium for both agricultural and non-agricultural land (forest, reclamation sites, and publication sites). As mentioned previously, the assumed soil type and the partition coefficient are important for this pathway.

In the case of beryllium, the assumed soil type for all land application sites is sand. This is a reasonable assumption, particularly for agricultural land. Loam soils (sandy loam, silty loam, silty clay loam) are predominant on agricultural land throughout the United States (sand and sandy loams predominate in the southeast). Of the loam soils, sandy loam has the highest pollution potential (U.S. EPA, 1992).

During the Comprehensive Hazard Identification study, the partition coefficient at the lower end of the range of partition coefficients for sand with a porewater pH of 5 was used. EPA concluded that because a reasonable soil type was used, it is appropriate to use any of the partition coefficients in the range of partition coefficients.

When the median partition coefficient value for sand with a porewater pH of 5 is used, Pathway 14 is not critical for beryllium (i.e., the cancer risk level is lower than 10^{-4}). For this reason, beryllium was not included on the final list of pollutants for the Round Two sewage sludge regulation for land application.

Boron

The critical pathway for boron for land application is Pathway 6 (animal foraging) for forest and reclamation sites. None of the pathways for agricultural land were critical for boron.

The uptake slopes used in the Pathway 6 analyses were obtained from non-sewage-sludge studies (i.e., crops for which the uptake slopes were obtained were not grown in sewage sludge-amended soil). EPA concluded that it is not appropriate to use those uptake slopes to estimate risks from boron in crops grown in sewage sludge-amended soils (see Policy Decision on page 2).

No other information is available on uptake slopes for boron. Because Pathway 6 was the only critical pathway for boron and because this pathway could not be evaluated using available information after the detailed examination of the critical pathways, EPA concluded that boron should not be on the list of pollutants for the Round Two regulation for land application.

Fluoride

Pathways 6 and 10 were critical for fluoride for both agricultural land and non-agricultural land (i.e., forest, reclamation sites, and public contact sites) in the Comprehensive Hazard Identification study. For Pathway 6 (animal foraging), the uptake slopes used in the analyses were obtained from non-sewage-sludge studies (i.e., crops from which the uptake slopes were obtained were not grown on sewage sludge-amended soils). EPA concluded it is not appropriate to use those uptake slopes to estimate risks from fluoride in forage grown in sewage sludge-amended soils (see Policy Decision on page 2).

No other information is available on uptake slopes for fluoride. Because Pathway 6 could not be evaluated using existing information after completion of the detailed examination of the critical pathways, EPA concluded that Pathway 6 is not critical. For this reason, fluoride was not included on the list of pollutants for the Round Two regulation for land application based on exposure through Pathway 6.

Pathway 10 (predator of soil organism) also was critical for fluoride for agricultural land and non-agricultural land. The TRV for this pathway was based on a NOAEL of 10 mg/L in drinking water administered to mice (Kanisawa and Schroeder, 1969). This was converted to a dietary equivalent value of 11 mg/kg-food using allometric equations (U.S. EPA, 1988). Results of other studies indicate that a dietary equivalent value for fluoride of 52 mg/kg-food resulted in changes in teeth and liver, and structural and functional changes in the kidney (Jankauskas, 1974; Lim et al., 1975; Roman et al., 1977, as cited in IARC, 1982).

The HEI for Pathway 10 is the predator of a soil organism (e.g., a shrew). The effect from the exposure in Pathway 10 is mild systemic changes (e.g., changes in teeth and liver).

Population effects from this exposure are unknown.

Because the effect for which the TRV is protective is mild systemic changes and not population effects, and because there is some evidence that fluoride is necessary for fertility in mice (Messer et al. 1973, as cited in IARC, 1982), EPA concluded that the TRV used in the Comprehensive Hazard Identification study was not appropriate. For this reason, and because no other relevant toxicological information on small mammals was available for Pathway 10, EPA concluded that Pathway 10 could not be evaluated for fluoride. Thus, Pathway 10 is not critical for fluoride.

The above information indicates that the critical pathways from the Comprehensive Hazard Identification study should not be the basis for including fluoride on the Round Two list of pollutants. For this reason, fluoride was not placed on the list of pollutants for the Round Two sewage sludge regulation for land application.

Manganese

Pathways 3, 6, 7, and 14 were critical for manganese for agricultural land. Pathways 3, 4, 6, 7, 10, and 14 were critical for manganese for non-agricultural land.

Pathway 3 is the child ingestion pathway. For agricultural land and public contact sites, a child between the ages of 1 and 6 is assumed to ingest 0.2 gram of sewage sludge (not the sewage sludge-soil mixture) daily. For forest and reclamation sites, a child between the ages of 4 and 6 is assumed to ingest 0.2 grams of sewage sludge daily.

The Reference Dose (RfD) for the Pathway 3 analyses in the Comprehensive Hazard Identification study was 0.005 milligrams of manganese per kilogram of body weight per day.

On May 1, 1996, the RfD for manganese in EPA's Integrated Risk Information System (IRIS) was changed. The current RfD for manganese in IRIS is 0.14 milligrams of manganese per kilogram of body weight per day for dietary exposure. As indicated in the Uncertainty and Modifying Factors section in IRIS, when assessing exposure to manganese from food, a modifying factor of one is used. When assessing exposure to manganese from drinking water or soil, a modifying factor of three is used. Because the HEI ingests sewage sludge, which is similar to soil, an uncertainty factor of three was applied to the RfD. The RfD for the Pathway 3 analyses should be 0.14 divided by 3, resulting in 0.05 milligrams of manganese per kilogram of body weight per day.

Using the current RfD for manganese, the RfD ratio for Pathway 3 is 0.4 for agricultural land and public contact sites, and 0.3 for forest and reclamation sites. Because these values are less than one, Pathway 3 is not critical for manganese. For this reason, EPA concluded that manganese should not be on the list of pollutants for the Round Two sewage sludge regulation based on exposure through Pathway 3.

The uptake slopes in Pathway 4, which was critical for forest and reclamation sites, were obtained using non-sewage-sludge studies (i.e., crops from which the uptake slopes were obtained were not grown in sewage sludge-amended soils). EPA concluded that it is not appropriate to use those uptake slopes for crops grown in sewage sludge-amended soils (see Policy Decision on page 2). Because there is no other information on manganese uptake slopes, manganese was not included on the Round Two list of pollutants based on exposure through Pathway 4.

Pathway 6 also was critical for manganese for agricultural land, forests, reclamation sites, and public contact sites. EPA concluded that manganese should not be included on the Round

Two list of pollutants based on exposure through this pathway because the uptake slopes used in the analyses were obtained from non-sewage-sludge studies. It is not appropriate to use those uptake slopes for crops grown in sewage sludge-amended soils (see Policy Decision on page 2).

The TRVs for Pathway 7, which was critical for manganese for agricultural land, forest, and reclamation sites, and for Pathway 10, which was critical for forest and public contact sites, are based on the results of studies using laboratory animals (i.e., rats). After reviewing the results in the original study (Laskey et al., 1982) used to develop the TRV, an error was found in the dietary value. The dietary value used to develop the TRV in the Comprehensive Hazard Identification study was 170 mg/kg-food. This value was divided by 10 to determine the TRV.

The dietary value in the Laskey study was 350 mg/kg-food. Thus, the TRV should have been 35 mg/kg-food instead of 17 mg/kg-food. When the revised TRV was used to calculate the RQs for Pathways 7 and 10, the RQ for Pathway 7 was 0.7 and the RQ for Pathway 10 was just 1. Therefore EPA concluded that manganese should not be included on the Round Two list of pollutants, because the RQ became less than one for one pathway, and just met the level of concern for the other pathway.

The final pathway that was critical for manganese is Pathway 14 (i.e., ground water). This pathway was critical for both agricultural land and non-agricultural land (i.e., forest, reclamation sites, and public contact sites).

Two of the important variables for this pathway are soil type and partition coefficient. As mentioned previously, EPA concluded that assuming a soil type of either sandy loam, shrinking clay, or sand is conservative. During the detailed examination of the critical pathways, the assumed soil type for Pathway 14 for manganese was sandy loam, not sand.

The partition coefficient for sandy loam with a porewater pH of 8 ranges from 8418 liter per kilogram to 15,774 liter per kilogram (Gerritse et al., 1982). Using any partition coefficient within that range is conservative. For the Pathway 14 analysis for manganese, when a value in the middle of the above range is used, Pathway 14 is not critical for manganese.

The above information indicates that after completion of the detailed examination of the critical pathways for manganese from the Comprehensive Hazard Identification study, none of the pathways are considered to be critical for agricultural land and non-agricultural land. For this reason, manganese was not included on the final list of pollutants for the Round Two sewage sludge regulation for land application.

Thallium

The critical pathway for thallium for agricultural land, forest, reclamation sites, and public contact sites was Pathway 3 - child ingestion of sewage sludge. In the Comprehensive Hazard Identification study, the ratio of exposure from Pathway 3 to the RfD for thallium was two.

The thallium RfD is based on the results of a 90-day study during which rats ingested soluble thallium salts in drinking water (IRIS, 1996). The uncertainty factor in the RfD is 3,000. In the case of the Pathway 3 analysis, the margin of safety is 1,500 (i.e., 3,000 divided by an RfD ratio of 2).

The absorption of metals like thallium in sewage sludge in the gastrointestinal tract after the sewage sludge is ingested by a child is expected to be lower than the absorption of soluble salts of thallium. For this reason and because the margin of safety for the Pathway 3 analysis is 1,500, EPA concluded that Pathway 3 was not critical for thallium. Thus, thallium was not

included on the final list of Round Two pollutants for land application for either agricultural land or non-agricultural land.

Tin

The critical pathway for tin for agricultural land, forest, and public contact sites was Pathway 7 (i.e., grazing animal that ingests sewage sludge directly). The TRV for tin was based on the results of a study in which female rats were fed 5 ppm tin in drinking water (Schroeder et al., 1968b). The observed effect in this study was decreased longevity.

The LOAEL reported in ATSDR (1992b) was 0.7 mg/kg/day, which is equivalent to a dietary value of 9 mg/kg-food. This value was divided by 10 to obtain a TRV for Pathway 7 of 0.9 mg/kg-food. When reviewing the original study on which the TRV is based, an error was found. The TRV should be 0.45 mg/kg-food, which means the RQ for tin for agricultural land, forest, and reclamation sites should have been four instead of two.

Studies other than the Schroeder et al. study (1968b) failed to find any effects in mice administered 5 ppm tin in drinking water (Schroeder and Balassa, 1967). In addition, other studies examining systemic effects in rats and mice found NOAELs an order of magnitude or more higher than the LOAEL from the Schroeder et al. study (1968b). Effects observed in these studies are not clear with respect to population effects from exposure to tin.

Because the LOAEL used to calculate the TRV for tin is from a study in which rats were administered tin in drinking water (absorption of tin in food or sewage sludge is likely to be lower than absorption of tin in drinking water); because results of other studies indicate that the NOAEL for tin is higher than the LOAEL from the Schroeder et al. study (1968b); and because

the population effects from exposure to tin are not known, EPA concluded that the TRV from the rat study should not be used as the TRV for the HEI in Pathway 7.

Because there is no other more appropriate information on the TRV for tin, Pathway 7 could not be evaluated for tin after completion of the detailed examination of the critical pathways. For this reason, Pathway 7 is not critical for tin, and tin was not included on the Round Two list of pollutants based on exposure through Pathway 7.

Titanium

The critical pathway for titanium for agricultural land and reclamation sites was Pathway 6 (i.e., animal foraging on sewage sludge-amended soils). The uptake slopes used in the Pathway 6 analyses were obtained from non-sewage-sludge studies (i.e., crops from which the uptake slopes were obtained were not grown in sewage sludge-amended soils). EPA concluded that it is not appropriate to use uptake slopes from non-sewage-sludge studies for forage grown in sewage sludge-amended soils (see Policy Decision on page 2).

No other information is available on uptake slopes for titanium. Because Pathway 6 could not be evaluated using available information, EPA concluded that Pathway 6 is not critical and that titanium should not be on the list of pollutants for the Round Two sewage sludge regulation for land application based on exposure through Pathway 6.

2.3.2 Surface Disposal

Antimony and Barium

The critical pathway for antimony and barium for surface disposal is the groundwater pathway. As mentioned in the above discussion of antimony for land application, one way to evaluate the RfD ratio (i.e., four for antimony and one for barium) for this pathway is to consider the uncertainty factor for the RfD with respect to the RfD ratio and the effect for which the RfD is protective.

The antimony and barium RfDs are based on an uncertainty factor of 1000. The margin of safety for a surface disposal site (i.e., surface impoundment) would be 250 (i.e., 1000 divided by 4) for antimony and 1000 (i.e., 1000 divided by one) for barium. EPA concluded that for antimony a margin of safety of 250 is sufficiently protective for the HEI (i.e., human) in this case because the effect upon which the RfD is based (i.e., changes in cholesterol and glucose blood levels) is not severe and is likely reversible. EPA also concluded that barium just met the critical pathway criteria. For these reasons, EPA concluded after completion of the detailed examination of the critical pathways that antimony and barium should not be on the Round Two list of pollutants for surface disposal based on exposure through the groundwater pathway.

Beryllium and Manganese

The groundwater pathway also was the critical pathway for beryllium and manganese for surface disposal. As mentioned previously during the discussion of the groundwater pathway for land application, two important parameters for the groundwater pathway are soil type and soil-water partition coefficient.

During the Comprehensive Hazard Identification study, the soil type for all surface disposal sites was assumed to be sand. EPA concluded that using a soil type of either sandy loam, shrinking clay, or sand is conservative.

A soil-water partition coefficient for sandy soil with a porewater pH of 5 was used in the Comprehensive Hazard Identification study for surface disposal. However, if the median partition coefficient for sandy loam with a porewater pH of 8 is used in the analysis, the groundwater pathway is no longer critical for beryllium and manganese for surface disposal.

EPA concluded that it is reasonable to use the sandy loam soil type in the surface disposal groundwater analysis. It is also reasonable to use the median value for partition coefficient in the range of partition coefficients for sandy loam soil in the analysis. When this value is used, the groundwater pathway is not critical for beryllium and manganese for surface disposal. For this reason, EPA concluded that those pollutants should not be on the final list of pollutants for the Round Two regulation for surface disposal based on exposure through the groundwater pathway.

2.3.3 Incineration

Results of the Comprehensive Hazard Identification study indicate that no pollutants warrant consideration for the list of pollutants for the Part 503 Round Two regulation for incineration. Dioxins/furans will be re-evaluated for the Part 503 use or disposal practices, including incineration, at the completion of EPA's dioxin reassessment.

2.4 POLLUTANTS RECOMMENDED BY OTHERS FOR THE ROUND TWO LIST OF POLLUTANTS

Prior to conducting the Comprehensive Hazard Identification study for the 31 candidate pollutants for the Round Two list of pollutants, EPA programs and experts from outside of EPA were contacted to obtain data (e.g., plant and animal uptake data) on the 31 candidate pollutants. Comments were received from Dr. George O'Connor from the University of Florida and Dr. Rufus Chaney from the U. S. Department of Agriculture (see Appendix D3).

Dr. O'Connor provided references on plant bioavailability for some of the candidate organic pollutants. Information from those references was used in the Comprehensive Hazard Identification study, where applicable.

Dr. Chaney also provided information on several of the candidate pollutants. He recommended that beryllium, boron, dioxins/furans, coplanar polychlorinated biphenyls, cobalt, fluoride, and iron be on the Round Two list of pollutants for land application.

With the exception of cobalt and iron, the pollutants that Dr. Chaney recommended for the Round Two list of pollutants for land application were evaluated in the Comprehensive Hazard Identification study. The results of the detailed examination of the critical pathways for those pollutants are presented in other sections of the Technical Support Document (U.S. EPA, 1996).

Both cobalt and iron were evaluated for the list of pollutants for the Part 503 Round One regulation for land application. Neither pollutant was include on the Round One list of pollutants.

Cobalt was not included on the Round One list of pollutants because the hazard index (estimated exposure divided by the reference dose) was less than one. Dr. Chaney stated that

results of cobalt feeding trials indicate that a cobalt concentration between 5 and 10 milligrams per gram of diet may be injurious to sheep and cattle. Cobalt was detected in nine percent of the samples from the National Sewage Sludge Survey. Using the 98th percentile concentration for cobalt from the NSSS (i.e., 104 mg/kg with non-detected values set equal to the minimum level) and the fraction of the animal's diet that is sewage sludge used in the Round One risk assessments (i.e., 1.5 percent), the 5-10 milligram per kilogram diet concentration for cobalt is not expected to be reached in an animal's diet from ingestion of sewage sludge. In addition, none of the updated information submitted by Dr. Chaney suggests that the original hazard index for cobalt would change. For these reasons, EPA concluded that cobalt should not be on the list of pollutants for the Part 503 Round Two regulation for land application.

Iron was not included on the Round One list of pollutants even though the hazard index for grazing animals that ingest the sewage sludge/soil mixture (i.e., Pathway 7) was 2.1. The rationale for not including iron on the Round One list was that the grazing animal index was based on a worst worst-case sewage sludge iron concentration and the assumption that five percent of the animal's diet is sewage sludge. If sewage sludge with a "typical" iron concentration (i.e., 28,000 mg/kg (U.S. EPA, 1985)) is used in the analysis, the hazard index for grazing animals is less than one. The hazard index for iron also is expected to be less than one if the fraction of the animal's diet from the risk assessment for the Round One regulation (i.e., 1.5 percent) and the 90th percentile concentration for iron from the NSSS (i.e., 41,800 mg/kg) are used to develop the index. For these reasons, EPA concluded that iron should not be on the list of pollutants for the Part 503 Round Two regulation for land application.

3. LIST OF POLLUTANTS FOR THE ROUND TWO SEWAGE SLUDGE REGULATION

On November 30, 1995, EPA submitted the list of pollutants for the Round Two sewage sludge regulation to the District Court in Oregon. The court notice is presented in Appendix D2.

After considering information from the Comprehensive Hazard Identification study; the rationales for deleting inorganic pollutants from the list of pollutants that warranted further consideration; and information received from others, EPA concluded that two pollutants should be on the list for each use or disposal practice. They are: dioxins/furans (all monochloro to octachloro congeners) and polychlorinated biphenyls (coplanar). The court notice indicates that EPA may, in the exercise of its discretion, determine to add or delete other pollutants to or from this list at the time the Round Two regulation is proposed.

In addition to the list of pollutants submitted to the court, EPA may change a limit for the pollutants in the Round One regulation during development of the Round Two regulation. For this reason, the Round One pollutants also are considered pollutants for the Round Two sewage sludge regulation.

Including the pollutants from the Round One regulation, the list of pollutants for the Round Two sewage sludge regulation by use or disposal practice is:

Land application

arsenic, cadmium, copper, lead, mercury, molybdenum, nickel, selenium, zinc, dioxins/furans, and coplanar polychlorinated biphenyls.

Surface disposal

arsenic, chromium, nickel, dioxins/furans, and coplanar polychlorinated biphenyls

Sewage sludge incineration

arsenic, beryllium, cadmium, chromium, lead, mercury, nickel, total hydrocarbons (or carbon monoxide), dioxins/furans, and coplanar polychlorinated biphenyls

Dioxins/furans were included on the list of pollutants for sewage sludge incineration even though results of the screening risk assessments indicate that no pollutant warrants consideration for the Round Two list of pollutants for incineration. EPA currently is conducting a reassessment of dioxins/furans. Because the results of this assessment are unknown, dioxins/furans were included on the Round Two list of pollutants for all use or disposal practices. At the completion of the dioxin reassessment, EPA may decide not to regulate dioxins/furans for a particular use or disposal practice or may decide to regulate dioxins/furans on an accelerated schedule.

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APPENDIX D1

LIST OF 31 CANDIDATE POLLUTANTS FOR THE ROUND TWO SEWAGE SLUDGE REGULATION SUBMITTED TO THE DISTRICT COURT IN OREGON

IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF OREGON

FRANK GEARHART, CITIZENS INTERESTED IN BULL RUN, INC., An Oregon Corporation, KATHY WILLIAMS, AND FRANCES PRICE COOK, Plaintiffs, NATURAL RESOURCES DEFENSE COUNCIL, INC., Intervenor Plaintiffs, ASSOCIATION OF METROPOLITAN SEWERAGE AGENCIES, Intervenor Plaintiffs, v. CAROL M. BROWNER Administrator, United States Environmental Protection Agency, Defendant.	Civil No. 89-6266-HO

NOTICE OF POLLUTANTS

Pursuant to paragraph 2 of the Consent Decree entered in this proceeding on September 5, 1990, as modified by this Court's September 14, 1992 order, the U.S. Environmental Protection Agency ("EPA") hereby gives notice that, based on available information reviewed to date, EPA presently intends to propose for regulation under section 405(d)(2)(B)(i) of the Clean Water Act, 33 U.S.C. § 1345(d)(2)(B)(i), the following pollutants:[1]

Acetic acid (2, 4, -dichlorophenoxy), aluminum, antimony, asbestos, barium, beryllium, boron, butanone (2-), carbon

[1] Based on information available at the time of proposal, EPA retains the discretion to either add or delete pollutants from the list of those that it currently intends to propose for regulation.

disulfide, cresol (p-), cyanides (soluble salts and complexes), dioxins/dibenzofurans (all monochloro to octochloro congeners), endsulfan-II, fluoride, manganese, methylene chloride, nitrate, nitrite, pentachloronitrobenzene, phenol, phthalate (bis-2-ethylhexyl), polychlorinated biphenyls (co-planar), propanone (2-), silver, thallium, tin, titanium, toluene, trichlorophenoxyacetic acid (2, 4, 5-), trichlorophenoxypropionic acid ([2 - (2,4, 5-)], and vanadium.

Respectfully submitted,

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Dated: May 21, 1993

APPENDIX D2

FINAL LIST OF POLLUTANTS FOR THE ROUND TWO SEWAGE SLUDGE REGULATION SUBMITTED TO THE DISTRICT COURT IN OREGON

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IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF OREGON

FRANK GEARHART, CITIZENS INTERESTED IN BULL RUN, INC., An Oregon Corporation, KATHY WILLIAMS, AND FRANCES PRICE COOK, Plaintiffs, NATURAL RESOURCES DEFENSE COUNCIL, INC., Intervenor Plaintiffs, ASSOCIATION OF METROPOLITAN SEWERAGE AGENCIES, Intervenor Plaintiffs, v. CAROL M. BROWNER Administrator, United States Environmental Protection Agency, Defendant.	Civil No. 89-6266-HO REVISED NOTICE OF POLLUTANTS

On May 24, 1993, pursuant to Paragraph 2 of the Consent Decree entered in this proceeding on September 5, 1990, as subsequently modified by this Court's orders, the U.S. Environmental Protection Agency ("EPA") submitted a Notice of Pollutants ("Notice"). The Notice stated that the Agency was considering proposing 31 pollutants for regulation under section 405(d)(2)(B)(i) of the Clean Water Act, 33 U.S.C. § 1345(d)(2)(B)(i). Paragraph 9d of the Consent Decree provides that the Agency may revise this list of pollutants if it concludes that regulations are not needed for some or all of the 31 pollutants. Based on current information, EPA has concluded that 29 of the listed pollutants need not be regulated: acetic acid (2, 4, -dichlorophenoxy), aluminum, antimony, asbestos, barium, beryllium, boron, butanone (2-), carbon disulfide, cresol (p-), cyanides (soluble salts and complexes), endsulfan-II, fluoride, manganese, methylene chloride, nitrate, nitrite, pentachloronitrobenzene, phenol, phthalate (bis-2-ethylhexyl), propanone (2-), silver, thallium, tin, titanium, toluene, trichlorophenoxyacetic acid (2, 4, 5-), trichlorophenoxypropionic acid ([2 - (2,4, 5-)], and vanadium.

Thus, EPA has concluded that only two of the listed pollutants warrant further consideration for regulation: dioxins/dibenzofurans (all monochloro to octochloro congeners) and polychlorinated biphenyls (co-planar). EPA may, in the exercise of its discretion, determine to add or delete other pollutants from this list at the time of proposal.

Respectfully submitted,

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Dated: November 28, 1995

CERTIFICATE OF SERVICE

I hereby certify that on this November 28, 1995 I caused a copy of the foregoing Revised Notice of Pollutants to be served by first class mail, postage prepaid, on the following counsel:

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APPENDIX D3

RESPONSES TO REQUESTS FOR DATA ON THE ROUND TWO CANDIDATE POLLUTANTS

United States Department of Agriculture | Agricultural Research Service | Beltsville Area Beltsville Agricultural Research Center | Beltsville, Maryland 20705

May 10, 1995

SUBJECT: Round 2 contaminants.

TO: Alan B. Hais, Chief, Multimedia Risk Assessment Branch.
Yogi Patel, Multimedia Risk Assessment Branch.

FROM: R.L. Chaney, USDA-ARS, Environmental Chemistry Lab. Rufus

I am responding to your letter of April 18, 1995 requesting information on plant uptake of these compounds or metals. I have written about the risks of most of these metals, and some of the organics over the last 10 years. I have huge amounts of literature on these elements, and several you appear to left our of consideration. Where uptake by plants is known to occur to any significant level from sludge-amended soils, these lesser-studied elements have often been examined by pot and field studies of Dr. Don Lisk and his collaborators (including me); they examined the sludges, soils, plants, and animal tissues using neutron activation (and atomic absorption or ICP) to analyze over 40 elements in numerous experiments.

I would hope that demonstrated iron toxicity to cattle and horses from high Fe sludges would put Fe on the list. Similarly, Co is a significant possibility based on food-chain injury to cattle and sheep. Fluoride is also a demonstrated risk from sludges, although mostly in the livestock grazing on surface-applied sludges. I had brought up these omissions in Round 1, so I am a little surprised that Fe and Co were not on the list. Even more surprised when Tl, Sn, and some of the others on your preliminary list were being considered when papers I have given EPA clearly show the lack of risk under any route of exposure to sludges. It would seem to me that your list partially came from the water people, and they base their concern on toxicity of water soluble salts in distilled water, or even on injected water soluble salts (e.g., Ag, Tl, Sn, etc.).

If there is a message to this letter, it is my concern about the need to have iron and cobalt on the thorough evaluation list. Comments below will provide a summary of the literature related to Pathway Analysis of Risk, and useful references.

If you want to reach me regarding these comments on the Round 2 List of Contaminants, I will be at my lab (301-504-8324) May 10 and 11, leaving

for England in mid-afternoon. I will return the evening of May 18, and be in the lab on May 19.

Aluminum: Al is severely phytotoxic to plants when soils remain at pH lower than about 5.2 for a number of years. Clays dissolve and Al^{3+} enters the cation exchange complex in soil. The water soluble Al^{3+} injures root initials, reduces root grown and reduces yield. Toxic Al in subsoils prevents plants from using water stored in subsoils. Al phytotoxicity is a common problem on agricultural and forest land. Addition of inorganic Al salts would allow development of Al phytotoxicity soon after acidification since precipitated $Al(OH)_3$ is present when the soil pH is over 5.2-5.5.

Little Al is absorbed and translocated into plant shoots, and even less into fruits and grains. Most plant Al is soil contamination from wind-blown dust in the field. Soil Al has lower bioavailability than do soluble salts of Al. Other than phytotoxicity, we know of no Pathway in which sludge-borne Al in soils will cause risk compared to unsludged soils. Al should be deleted from the list.

Antimony: In the 1970s and 1980s, Dr. Lisk and his collaborators used neutral activation to measure many elements in plants, sludges, and soils., in pot and field experiments. There were some limitations in these studies. However, the results with antimony were useful to your need. The normal chemical form of antimony (Sb^{3+}) in soils is quite insoluble at normal soil pH levels. Plant leaves, fruits, or grains had unchanged Sb concentration even when soil Sb was significantly increased by applied sludges; and animals did not accumulate Sb from sludge grown crops of Chaney et al. (1978). Sb has little toxicity to animals or plants. It is used some medications. I believe Sb should be deleted from your list.

Barium: In normal soils, which have adequate amounts of Ca and Mg even when sludges are utilized on land, Ba is an exchangeable cation which is pretty insoluble when sulfate is at the levels in soil required to produce high yielding crops. Plant shoots have little response to added sludge Ba, again from the data of Lisk et al. (including the Chaney et al., 1978b) paper on chard fed to Guinea pigs) show no risk of injury or residue transfer to livestock or wildlife. Barium occurs at unusual levels in a few crop species, including Brazil nut, but Lisk and other researchers have not shown significant increase in crop Ba on sludge-amended soils.

Beryllium: Added to soils as a soluble salt, Be has low phytoavailability. Lisk found little evidence that sludge Be moved into plants. And no evidence that Be accumulated in animal tissues when sludge grown crops were

fed to test animals. Be may require full evaluation because of known possible uptake and important industrial toxicology information. However, only Lisk may have measured Be in sludge research studies, and I'm not sure even he did. My comments are based on basic studies in which Be salts were added to soils for plant studies, and the NRC (1980) book on livestock.

Boron: Boron is important in agriculture and the environment because it is phytotoxic. High water soluble B in soils is accumulated by most plants, and they suffer phytotoxicity at foliar B levels which are not high enough to be toxic to livestock chronically fed the crops suffering B toxicity. There is reasonably good evidence that B is required by animals, and that dietary B is generally low. I can perceive no risk except phytotoxicity from sludge B; Lisk et al. provided good evidence of lack of B toxicity or food-chain accumulation of boron.

Only a few studies of sludge or effluent use on cropland or forests has shown B phytotoxicity. In one, a sensitive crop received spray-applied effluent with over 1 mg B/L. In a sludge study, a sensitive crop suffered B phytotoxicity when a sludge containing glass fiber wastes was land applied. Slow dissolution of B from the glass fibers caused excessive B uptake. More B tolerant crops would not have been expected to suffer any effects of biosolids-applied B in that study. I summarized sludge and compost B data in the Chaney and Ryan (1993) paper from the Ohio Composting Conference (see at end of reference section). The appropriate analysis of sludge boron risk will require extraction of "hot water soluble" boron. Based on substantial animal tolerance of B (NRC, 1980), only the phytotoxicity pathway will require risk assessment.

Fluoride: A few sludges contain very high levels of F, resulting from computer chip manufacturing wastewaters (HF is used to leach Si from marked surfaces of the chip), and from aluminum smelting processes. One sludge containing about 5% F was studied by Davis, 1980. He found this sludge could induce F phytotoxicity in ryegrass from soil applied high-fluoride sludge. Generally, foliar exposure of plants to HF causes high accumulation of F in the plants, which in turn poisons livestock. It is widely shown that animals are at much greater fluoride risk from sludge of soil ingestion than from plant uptake.

In the Denver sludge feeding studies (Klenholz et al. and Baxter et al.), CaF (the solid phase F compound in sludges) could be dissolved in the digestive system of cattle, and it could cause bones to become brittle and teeth to break. Analysis of sludges, using some selected

concentration below which no harm is expected to plants or livestock, will provide the protection needed for humans, livestock, and wildlife. Only highly contaminated soils will have phytoavailable F.

Manganese: Few sludges contain high levels of Mn (> 1500 ppm DW). In fact, the principle problem regarding sludges is the induction of Mn deficiency when lime-treated sludges are used on coastal plain soils (historically depleted of total soil Mn, so they are more susceptible to lime-induced-Mn deficiency). I reviewed Mn in the Chaney and Ryan (1993a) paper at the Ohio Composting Conference.

We have been testing use of Mn amendments to sludges to prevent induced-Mn deficiency from lime-treated sludges, and have found no evidence of plant toxicity when limed sludge was enriched in Mn by about 6,000 ppm. Al Rubin heard our seminar on May 3 at the Maryland Department of the Environment.

When high Mn soils are strongly acidified (pH $\leq$ 5.4), Mn^{2+} accumulates among the exchangeable cations, and can cause phytotoxicity to sensitive crops. However, except for rare Mn hyperaccumulator species, plants suffer phytotoxicity and leaves remain low in Mn such that they do not comprise chronic toxicity risk to livestock or wildlife. Farmers are forced to add limestone to raise soil pH to prevent Mn phytotoxicity in strongly acidic high Mn soils. I believe that the added risk from sludge-borne Mn is trivial.

Silver: Silver is toxic to animals when injected, but not when ingested with a complete diet; AgCl precipitate is formed in the gut, and Ag is not toxic. When Ag is added to soils, it is strongly precipitated and adsorbed by the soils. Plants accumulate only traces of Ag, and no evidence of plant uptake which might comprise a chronic ingestion risk has been found. Most environmental concern about Ag results from toxicologists testing soluble Ag salts in purified waters. Never from sludge. Even when sludge was fed to livestock, sludge Ag was not toxic nor accumulated. Silver should be deleted from the list.

Thallium: Although Tl appears to comprise a risk to plants or the food-chain from deposition of aerosols on plants, there is little evidence that sludge-applied Tl is moved into edible plant tissues. Again, the studies of Lisk et al. using neutron activation provide adequate evidence that sludge Tl has not been found to comprise risk. Tl can be emitted from incinerators, and cement manufacturers commonly emit Tl and cause local enrichment of soils.

Tin: Sn is normally Sn^{4+} in the soil environment, and very insoluble. Like Ti and Cr, Sn is a good label for non-absorbed soil in the diet. Sludges seldom have really high levels of Sn, and no evidence of plant uptake of Sn from sludge-amended soil has been reported. Lisk included Sn in his studies by neutron activation. Actually, sludge Sn is not a risk to livestock which ingest sludge, in strong contrast with sludge Fe and F. Tin should be deleted from the list.

Titanium: Ti is usually Ti^{4+} in soils, and is very insoluble as TiO_2. Soil Ti is not found inside plants, only as soil or dust contamination on the plants. Soil/Sludge Ti is so insoluble that it does not comprise risk even when ingested by livestock. Titanium should be deleted from the list.

Vanadium: In nutrient solutions, certain unstable V salts can be accumulated by plants, and vanadate interferes with ion uptake by ATPase enzymes in the roots. Little V is translocated to edible crop tissues. The Lisk work usually showed that V was not accumulated by crops, nor in animal tissues. Vanadium should likely be deleted from the list.

Iron: I am a little concerned that no one in your team chose to enter Fe (iron) or cobalt (Co) into the Round 2 review. In 1976-1979, a cooperative study in Maryland allowed us to characterize Fe toxicity to cattle fed high Fe (11%) and low Cu sludges on pastures. When a sludge or compost with only about 4% Fe was surface-applied on pastures or added to feeds in a feeding study with cattle, they did not cause the Fe toxicity, but some accumulation of Fe in the spleen, liver, and duodenum was observed. Several other controlled feeding studies in the US did not find evidence of Fe toxicity from ingested sludges with 1-2% Fe, and seldom found Fe accumulation is tissues. The usual action of excessive Fe intake is to induce chronic Cu deficiency which causes joint disease. Because Fe has poisoned livestock in several sludge experiments, and if high Fe sludges are found by monitoring, the sludge can be required to be injected or incorporated rather than left on the surface, avoidance of sludge Fe risk is comparatively easy. When the ferrous Fe in anaerobic sludges becomes oxidized in the soil, or during composting, the ferric Fe has much lower solubility or toxicity to cattle. So the method of sludge processing and the concentration of Fe in the final product are important in prediction of animal risk. Humans seldom ingest sludges which are freshly anaerobic, and no evidence of human risk from sludge Fe has been identified.

In the Oklahoma miniature horses case, the horses were alleged to have suffered Fe toxicity, but the soil appears to have been the major source

of the Fe exposure. Historic observations of induced Cu deficiency on lateritic or other high Fe soils has been reported in cattle from many locations. Another case in Virginia may have comprised Fe poisoning, but the details of the source of excess soluble Fe remain unclear. One common symptom of Fe toxicity is red coloration of the duodenum from ferritin accumulation. Tissues (liver, kidney, spleen, blood/serum) have increased Fe concentrations when higher Fe sludges are ingested by livestock.

Cobalt: Because sludges normally do not contain high Co concentrations without unusual industrial discharge, no Co problems have been observed in sludge research. However, my analysis of the "Soil-Plant Barrier" indicated that plants could tolerate higher Co concentrations than can be tolerated by ruminant livestock. Apparently vitamin B_{12} is formed in the rumen, and this form of Co causes toxicity in the livestock. Co feeding trials (see NRC, 1980) have shown that 5-10 ppm Co in diets injures sheep and cattle. I have done a substantial risk assessment on Co for a compost to be made from wastewater treatment biosolids at a manufacturing plant of DuPont, and this could be made available to you upon request. Thus, although no adverse effects of sludge-applied Co have been reported to date, it is at least possible to poison ruminants by Co in forage plants. Analysis can identify the very few high Co sludges and require practices to prevent adverse effects.

So, of all the elements you have listed, Fe and F are the only ones with sludge research showing a toxic environmental effect from sludges utilized on land. Please add Fe and Co to the list now. And delete Al, Sb, Ba, Mn, Ag, Sn, Ti, and V.

Organics with substantial vapor pressure (toluene; 2-butanone; methylene chloride; phenol; 2-propanone; ~~toluene~~) are expected to be volatilized or biodegraded during activated sludge treatment of the wastewater, and trace residues will collect in the sludge. Each of these compounds is readily metabolized by soils, with short half-lives. These should be deleted because Round 1 consideration of other volatile compounds showed that no residue reached humans or livestock.

The 2,4-D, 2,4,5-T, and 2-(2,4,5)-TP are residues of pesticides which have lower use today because of their adverse effects in Agent Orange which was contaminated with dioxins produced as byproducts. These compounds are usually sprayed on the plant, and metabolized fairly rapidly by tolerant plants, but slowly by sensitive plants. These reactions are well reported in pesticide applications at EPA. Because these are not very lipophilic, they are usually

biodegraded rather than persistent in soils.

Cyanides can accumulate in sludges after precipitation of ferricyanide by other metals. Soluble cyanide is present only at very low concentrations. Sludges have low levels of total CN, and essentially all sludge/soil cyanide is found to be bound to Fe.

I know little about CS_2. But these is little evidence it would survive aerobic treatment of the water.

Co-planar PCBs, PCNB, Dioxins, Dibenzofurans, and endosulfan are persistent halogenated hydrocarbons. Detailed evaluation will be required for these compounds. But the toxicity endpoints for the halogenated hydrocarbons are seldom reached from these compounds in land-applied sludges. The Madison, WI, studies showed that no significant transfer of sludge-applied PCBs was observed in above ground plant biomass = forages. Direct ingestion of sludges allows digestion of these compounds from the sludge. Accumulation of dioxins in earthworm-food-webs is expected, but not yet shown to induce toxicity to animals.

Nitrate accumulates in fields with aerobic soils after sludge has been incorporated. Some plants accumulate excessive levels of plant nitrate (spinach, beet), and comprise nitrate-poisoning risk to infants. Further, excessive nitrate accumulation in some forage crops can poison livestock. Nitrite seldom accumulates unless some toxic factor inhibits nitrification of the nitrite. Because sludge application rate is limited to the fertilizer requirement of the crop, nitrate and nitrite so not require regulation.

I heard a story about tungsten toxicity in a field study in the UK, but no papers were prepared from the thesis and report to the funding agency. I hope to visit the University of Sheffield and obtain a copy of the thesis on May 12. Dr. Steven McGrath hypothesized that tungstate interfered with use of molybdate in plants by competition as a co-factor for an enzyme involved in N-fixation or nitrate reduction by the plants.

Thus, several elements on the list are of potential importance because of their phytotoxicity rather than food-chain-transfer. These include Al, B and F. Some comprise food-chain risk to livestock which graze the fields (F; and possibly Be, Ba, and Be). Some are not dangerous to livestock even when ingested (Ti, Sn, Sb, and probably Sb). As noted above, Fe and Co also comprise risk until sludge analysis provides the management information needed to prevent risk.

As shown by the Round 1 contaminants, Se and Mo are accumulated by forage crops such that they comprise risk to the livestock rather than to humans consuming garden crops in Pathway 3. Mo needs to be finalized. Several scientists have been conducting studies on Mo uptake by crops on sludge-amended soils. High sludge Fe reduces Mo phytoavailability as noted in my 1991/1992 comments on 503 Mo limits in which I clarified errors in the database on Mo uptake from sludges. The potential role of sludge Fe (and Al) in binding sludge F can sharply reduce fluoride risk assessment for sludges.

Based on widely accepted data about the trace elements on this list, I believe that the following should be deleted from Round 2 now (Al, Sb, Ba, Mn, Ag, Tl, Sn, Tl, and V, and the volatile organics). Others are only a risk in sludge is ingested (Fe, F), and some are sufficiently phytotoxic (based on field studies with sludge) that they might be regulated to avoid phytotoxicity): Al, B, Mn. And Fe should be added to include a well characterized sludge risk from anaerobic treatment conditions. Cobalt is theoretically toxic to ruminant livestock after it is accumulated in forage plants.

Please feel free to call or write me for further information if needed. I enclose several references which cover the Lisk/Furr papers, and have several databases on the sludge-trace element literature in WordPerfect 5.1 which contain references on these rarer elements in sludges.

PLEASE CONFIRM RECEIPT OF THIS MEMORANDUM.

References cited in letter to Hais:

Boyer, K.W., J.W. Jones, D. Linscott, S.K. Wright, W. Stroube and W. Cunningham. 1981. Trace element levels in tissues from cattle fed a sewage sludge-amended diet. J. Toxicol. Environ. Health. 8:281-295.

√REF-VER/Copy [Sewage Sludge—CO: Baxter et al.] "The levels of 20 elements (Al, Ca, Cd, Cl, Co, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, Rb, Sb, Se, V, and Zn are reported for kidney, liver, muscle, spleen, and brain tissues taken from two groups of 6 steers per group in a feeding study conducted at Colorado State University. The control group was fed a normal feedlot cattle ration and the test group was fed the same ration amended with 12% (by weight) air-dried municipal sewage sludge. elemental levels are also reported for the control and test diets, control and test feces, and sewage sludge added to the diet. All samples were analyzed by ICP-plasma emission spectroscopy and neutron activation analysis. Brief descriptions of the analytical methods are included. the levels of all metals determined were elevated in the test diet (as much as 19-fold for Cd) compared with the control diet. The levels of Pb and Cd in kidney and of Pb, Cd, and Cu in liver in the test animals were high enough to cause concern from a toxicological standpoint if these tissues were consumed regularly by humans. None of the levels of any of the other elements in the control and test animals tissues were high enough to cause similar concern with respect to human consumption."

Samples from the 2nd study, with Ft. Collins sludge when it was still high in Cd and Cu. Wet ashed samples. For higher concn metals, ran on ICP directly. For lower concn metals, adjusted to pH near 5 and used chelex resin to collect metals from a larger aliquot, and then acid stripped the

metals into small volume for analysis. Co was by NAA. Co in kidney of (Control/Test) were 0.020/0.041 μg/g FW; liver Co: 0.047/0.077; Muscle Co: 0.07/0.017; Spleen Co: 0.02/0.02; Brain: 0.009/0.019. Diet contained 0.09/0.43 ppm Co, sludge, 2.5 ppm; and feces:0.43/1.60 ppm DW. ✓RLC•Ω

Capar, S.G., J.T. Tanner, M.H. Friedman and K.W. Boyer. 1978. Multielement analysis of animal feed, animal wastes, and sewage sludge. Environ. Sci. Technol. 12:785-790.

✓REF-VER/Copy [Sewage Sludge—CO: Baxter et al.] "Animal excreta and sewage sludge are currently being used as animal feed ingredients on an experimental basis. The levels of 30 elements are reported for a typical cattle feedlot diet, two dried cattle manures, a commercial cattle waste product, tow dried poultry manures, and a metropolitan sewage sludge. The analyses are conducted using neutron activation analysis, induction coupled plasma spectroscopy, atomic absorption spectroscopy, and anodic stripping voltammetry. The levels of most inorganic elements are considerably higher in animal wastes and sewage sludge than in traditional animal feeds. For most elements the levels determined by several techniques are in good agreement. Problems of loss of lead with precipitate formation, accurate quantitation of elements present in high levels, and obtaining homogeneous samples for analysis are discussed."

Worried about element contamination of sludge and manure if these are used as feed ingredients. thus analyzed many elements using newer techniques (at that time). The feedlot diet contained 0.10 ppm Co, while manures contained 1.1-2.2 ppm Co, and Denver sludge, 7.1 ppm Co. Also analyzed As, Ba, Be, Br, Cd, Cr, Cu, Eu, Hg, La, Mn, Mo, Pb, Rb, Sb, Sc, Se, Sn, Ti, V, Zn, Al, Ca, Cl, Fe, K, Mg, Na, and P. Found considerable contamination of samples with residues of a homogenizer (for Co, Cr, and Ni from stainless steel). Note need for studies of risk and health of animals which consume these contaminated materials. ✓RLC•Ω

Chaney, R.L. and J.A. Ryan. 1993. Heavy metals and toxic organic pollutants in MSW-composts: Research results on phytoavailability, bioavailability, etc. pp. 451-506. *In* H.A.J. Hoitink and H.M. Keener (eds.). Science and Engineering of Composting: Design, Environmental, Microbiological and Utilization Aspects. Ohio State University, Columbus, OH.

Chaney, R.L., G.S. Stoewsand, A.K. Furr, C.A. Bache and D.J. Lisk. 1978b. Elemental content of tissues of guinea pigs fed Swiss chard grown on municipal sewage sludge-amended soil. J. Agr. Food Chem. 26:994-997.

✓ [Sewage Sludge-USDA: Chaney et al.—FEEDING] ✓REF-VER/Copy [(Co in Soil/Plant: Misc. Auth.) Sewage Sludge—USDA: Chaney et al.—Bioavailability] Because we used neutron activation to analyze Co, data are available. "Swiss chard was grown on soil amended with municipal sewage sludges from Baltimore and Washington, DC. The harvested crops were fed at 20 or 28% of diet to guinea pigs for 80 days. Samples of soil, sludges, plant, and animal tissues were analyzed for up to 43 elements. The elements Br, Ca, Co, Eu, Fe, Ni, and Sr were found at higher concentrations in tissues of animals fed the chard cultured on sludge-amended soil than in control animals. Composting sludge prior to amending the soil appeared to render certain elements such as Cd, Cu, Ni, and Zn less available to Swiss chard subsequently grown."

COBALT SUMMARY: Chard was grown on plots of Woodstown silt loam amended with 56 Mg/ha of Baltimore digested sludge, 112 Mg/ha of Blue Plains digested sludge, and 224 Mg/ha of composted digested Blue Plains sludge, and on control. Because the BP compost included some serpentine rock chips, compost and chard were higher in Co than the other sludges: Soil = 9.1 ppm; Balto = 9.4 ppm; BP Dig = 8.0 ppm and BP Compost = 15 ppm DW. The chard (harvested at maturity, washed, rinsed, freeze-dried and ground): Control = 0.4; Balto = 0.8; BP Dig = 2.2; and BP Comp = 1.1 mg Co/kg DW. These results follow the pH of the plots rather than the Co content of the "sludge" or the amended soils. pH at harvest was 6.6, 5.0, 5.7, and 6.7 indicating that compost acted as a liming agent in contrast with sludge. Kidney of one of the 4 replicate

guinea pigs was analyzed for many elements, and all kidney and liver samples were analyzed for Ni, Pb, and Cd. Kidney Co was: Control = 0.6; Balto = 0.7; BP Dig = 1.0; BP Comp = not reported. No significance test was possible on the Co data. Ni was increased in Baltimore chard and kidney/liver of the guinea pigs. Although all sludge grown chard was higher in Cd than the control, no increase was found in kidney or liver! Attribute this to presence of Zn in same tissue. The guinea pigs did equally well on all sources of chard, growing 450 g in the 80 days. ✓RLC•Ω

Davis, R.D. 1980. Uptake of fluoride by ryegrass grown in soil treated with sewage sludge. Environ. Pollut. B1:277-284.

Decker, A.M., R.L. Chaney, J.P. Davidson, T.S. Rumsey, S.B. Mohanty and R.C. Hammond. 1980. Animal performance on pastures topdressed with liquid sewage sludge and sludge compost. pp 37-41. In Proc. Nat. Conf. Municipal and Industrial Sludge Utilization and Disposal. Information Transfer, Inc., Silver Spring, MD.
• RLC•Ω

Francois, L.E. 1986. Effect of excess boron on broccoli, cauliflower, and radish. J. Am. Soc. Hort. Sci. 111:494-498.

Francois, L.E. and R.A. Clark. 1979. Boron tolerance of twenty-five ornamental shrub species. J. Am. Soc. Hort. Sci. 104:319-322.

Furr, A.K., W.C. Kelly, C.A. Bache, W.H. Gutenmann, and D.J. Lisk. 1976. Multi-element absorption by crops grown on Ithaca sludge-amended soil. Bull. Environ. Contam. Toxicol. 16:756-763.
✓ RLC•Ω

Furr, A.K., T.F. Parkinson, D.C. Elfving et al. 1981. Element content of vegetable and apple trees grown on Syracuse sludge-amended soils. J. Agric. Food Chem. 29:156-160.
✓ RLC•Ω

Hogue, D.E., J.J. Parrish, R.H. Foote, J.R. Stouffer, J.L. Anderson, G.S. Stoewsand, J.N. Telford, C.A. Bache, W.H. Gutenmann and D.J. Lisk. 1984. Toxicologic studies with male sheep grazing on municipal sludge-amended soil. J. Toxicol. Environ. Health 14:153-161.

✓REF-VER/Copy [Heavy Metals in Soil/Plants: Lisk et al.—SLUDGE] "Growing sheep were grazed for 152 days on grass-legume forage growing on soil that had been amended with municipal sewage sludge from Syracuse, NY, at 224 metric tons/ha. Cd was higher, but not significantly ($P > 0.05$), in tissues of sheep fed the sludge-grown forage as compared to controls. No significant differences between the sludge or control treatments were found in weight of the complete or cauda epididymis or in % progressive motility of cauda epididymal sperm. The sludge-treatment group had significantly larger testes ($P<0.025$) when expressed as a percentage of body weight, and higher blood uric acid values ($P<0.05$). There were no observable changes in tissue ultrastructure of liver, kidney, muscle, or testes as examined by electron microscopy in either of the treatment groups. There were no significant differences for rate of animal weight gain, carcass weight, dressing percentage, or quality or yield grade of the carcass between the treatment groups."

Syracuse sludge. April 1980, applied weathered (1 yr) sludge to subsoil of Chenango gravelly loam, pH 7.1. Amended soil was pH 6.7. Collected grass-legume hay for feeding studies in 1980 and 1981. In 1982, used for grazing study. Had been planted with alfalfa, birdsfoot trefoil,

timothy, and bromegrass. 3 month old 'Morlam' sheep used to graze the pastures for 152 days. Each animal was also fed 250 g feed concentrate daily, and ad lib water. Composite soil from field Sludge contained 83 ppm Cd; forage 0.09 vs. 1.14 ppmDW Cd. Feed concentrate contained 0.21 ppm Cd. Kidney contained 0.55±0.14 ppmDW Cd vs. 0.83±0.17 NS; liver contained 0.22±0.04 vs. 0.40±0.08 NS; muscle contained 0.03±0.01 vs. 0.09 ±0.04 ppmDW Cd NS. Rate of gain was higher for sludge than control animals NS. ✓RLC•Ω

Kienholz, E.W., G.M. Ward, D.E. Johnson, J. Baxter, G. Braude and G. Stern. 1979. Metropolitan Denver sewage sludge fed to feedlot steers. J. Anim. Sci. 48:735-741.

✓REF-VER/Copy [Sewage Sludge—CO: Baxter, Kienholz, et al.] "Feedlot steers received 0, 4, or 12% Metropolitan Denver sewage sludge on a dry weight intake basis for a 94-day finishing period. The sludge was anaerobically digested primary sludge that had been treated with polyelectrolyte to aid in dewatering during vacuum filtering. It was then dried to 35% water prior to mixing into the pelleted diet given the steers. Cattle (6 on each treatment) were slaughtered and kidney, liver, muscle, bone, brain, blood, lung, spleen, and fat were analyzed for As, Cd, Cu, Hg, Mo, Ni, Pb, Se, and Zn.

"Growth of the sludge animals was less than controls ($P < 0.025$) because sludge, apparently, provided no energy. Sludge ingestion caused no pathology. All 10 inorganic elements except Ni were increased in one or more body tissues following the 94 day sludge ingestion. Percentage whole carcass retentions of ingested minerals were estimated as follows: 0.2% As, 0.04% Cd, 0.3% Cu, 0.07% Hg, 0.2% Mo, <0.006% Ni, 0.6% Pb, 1.3% Se, 0.2% Zn, and 32% F. Steers retained low amounts of the toxic heavy metals from sludge ingestion."

Sludge contained (ppmDW): 1.3 As, 21 Cd(diets 0.025, 0.65, and 1.9 ppm), 710 Cu(diets 3.2, 31, and 86 ppm), 11 Hg, 40 Mo, 125 Ni, 780 Pb(diets 0.6, 26, and 77 ppm), 5.4 Se, 1500 Zn, and 200 F. Diet was pelletted corn + cottonseed mean + molasses + limestone + NaCl. corn silage ad lib. Bone samples were taken from the proximal half of the tarsal bone. Samples digested with low metal acids. For many elements (not kidney or liver), sample metals were extracted by APDC, crystals collected, and filtered. Taken into small volume for analysis. Carbon rod used for some samples. Good QA/QC program. At 12% sludge, As was increased in liver, Cd in liver and kidney, Cu increased in liver, Hg increased in liver, kidney and muscle, Mo increased in bone and liver, Pb increased in liver, kidney, bone, and blood; Se increased in blood; Zn increased only in liver. At both rates, F increased in bone. Ni did not increase in any tissues.

Pb in tissues: Liver 0.2a 3.3b, 4.6c ppmDW for 0/4/12% sludge; kidney: 0.9a 12.2 b 15.8 b; Muscle: 0.2 . 0.2; bone:1a, 4b, 11c; blood: 0.12a, ., 0.82b; fat:0.16, ., 0.16. Cd in tissues: liver: 0.2a 0.5b 0.4b; kidney: 1.1a 2.5b 2.4b; muscle: <0.01, ., <0.01. Hg: Liver:0.01a 0.06b 0.14c; kidney 0.1a, 0.45b, 0.9c. Cu: liver: 124a, 260b 240b. ✓RLC•Ω

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NRC (National Research Council). 1980. Mineral Tolerance of Domestic Animals. National Academy of Sciences, Washington, D.C. 577pp.

- RLC•Ω

Rea, R.E. 1979. A rapid method for the determination of fluoride in sewage sludges. Water Pollut. Contr. 78:139-142.

Sanson, D.W., D.M. Hallford and G.S. Smith. 1984. Effects of long-term consumption of sewage solids on blood, milk and tissue elemental composition of breeding ewes. J. Anim. Sci. 59:416-424.

✓REF-VER/Copy [Sewage Sludge-NM: Smith et al.] "Fine-wool ewes received for 2 yr a complete pelleted diet (11% protein) or the basal diet fortified with 3.5% cottonseed meal (CSM,

12% protein) or gamma-irradiated (1 megarad) dried solids (SS, 12% protein) from primary (undigested) sewage (Las Cruces, NM municipal sewage). Five ewes fed each diet were sampled to determine Ag, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Pb, and Zn in blood, milk and tissues. Tissues and blood were sampled at slaughter 40 days after weaning of lambs. Mean whole blood mineral concentrations were similar ($P > 0.05$) among treatments 3 d postpartum; however, at 42 days after lambing both basal and sewage fed ewes had elevated blood Ca compared with ewes fed CSM. No biologically important differences were detected in the concentrations of elements in milk. Ewes fed SS had lower ($P<0.05$) flood Fe than animals in the other groups. Sewage-fed ewes also had higher ($P<0.05$) liver Fe (1092 ppmDw) than basal-fed ewes (626 ppm) whereas Fe in CSM-fed ewes (873 ppm) was similar to both. Basal-fed animals had 1.1-1.3 times more ($P<0.05$) liver Mg and 2-to-3-fold higher liver Na than CSM or SS. Livers from SS-fed ewes had higher concentrations ($P<0.05$) of Cd (1.5-1.5-fold) and Pb (1.4-1.9-fold) than livers from CSM or basal-fed ewes. Cd was 1.2-1.5-times higher ($P<0.05$) in kidneys from ewes receiving the sewage product, but all values were less than 1 μg/g. Lead was not detectably increased in kidney samples. Spleen Ca, Fe, and Ni and muscle Ca were increased due to feeding SS; however, no elements in bone samples from SS-fed animals were elevated above the control groups. Consumption of a diet containing 7% SS throughout a 2-yr period had only minor effects on element contents of blood, milk, or tissues."

Sludge contained: 20 Ag, 3.2 Cd, 361 Cr, 405 Cu, 5280 Fe, 99 Mn, 11 Ni, 150 Pb, and 606 ppmDW Zn. Blood Cu or Zn not really changed by SS ingestion. Milk Cu dropped with SS at the later sampling time. Liver Fe was (basal/CSM/SS) 626/873/1092; Co, 0.9/0.9/0.9; Cu 32/30/37;Zn 39/41/35; Cd 0.5b/0.6b/0.8c; Pb 2.1b/2.9b/4.0c. Kidney: Cd 2.4b/3.1b/3.7c; Pb 3.6b/1.9c/3.7b. Bone Pb: 21/15/18 NS. ✓RLC•Ω

Sanson, D.W., D.M. Hallford and G.S. Smith. 1984. Effects of dietary sewage solids on feedlot performance, carcass characteristics, serum constituents, and tissue elements of growing lambs. J. Anim. Sci. 59:425-431.

✓REV-VER/Copy [Sewage Sludge-NM: Smith et al.] "20 fine-wool wether lambs were allotted randomly at weaning to be fed a conventional diet (CD) formulated for growing lambs, or the same basal mixture plus dried gamma-irradiated solids from primary sewage sludge (SS) incorporated as 7% of the dry matter. Feedlot performance was chemical elements in whole blood were monitored during 90 days, after which lambs were slaughtered and carcass data were collected. Concn. of Ag, Ca, Cd, Co, Cr, Cu, fe, K, Mg, Mn, Na, Ni, P, Pb, and Zn were measured in livers, kidneys, bones, spleens and muscles. SS in the diet did not affect performance appreciably, although dressing percentages from lambs fed SS were 4% lower than Cd-fed animals ($P<0.05$). rib eye areas, fat thickness quality and yield grades were similar ($P>0.05$). element concentrations in whole blood at weaning, after 56 days of the feeding trial and at slaughter did not differ ($P>0.05$) between dietary groups. Serum chemistry determinations showed no biologically meaningful patterns related to diets. Lambs fed SS had higher ($P<0.05$) concn. of Cu in livers (51.1 vs. 34.3 μg/g) and Pb in kidneys (4.0 vs. 2.2±0.3 μg/g and lower Mg in kidneys. None of the elements in spleen and muscle tissue differed ($P>0.05$) between diet groups. Lambs fed SS had elevated ($P<0.05$) bone Co, Cu, Fe, K, and Na compared with those of CD. Lead concn. in bone were increased ($P<0.05$) by Ss over CD (30.5 vs. 26.3), but Cd and Zn did not differ. A feedlot diet with 7% SS did not appear to adversely affect growth or carcass characteristics of lambs. Serum clinical profiles and chemical elements in blood and tissues were affected negligibly by SS as 7% of the diet."

Sludge composition averaged: 3 Cd, 470 Cu, 9233 Fe, 110 Mn, 9 diet consumption, and lower gain rates. Blood Cu not affected by sludge ingestion. Liver contained: Cd <0.07/0.07 ppmDW; Cu 34.3/51.1; Fe 179/190; Pb 2.5/3.5; Kidney: Cd <0.07/<0.07; Pb 2.2a/4.0b; bone: Pb 26.3a/30.5b. ✓RLC•Ω

Smith, G.S., D.M. Hallford and J.B. Watkins, III. 1985. Toxicological effects of gamma-irradiated sewage solids fed as seven percent of diet to sheep for four years. J. Anim. Sci. 61:931-941.

√REF-VER/Copy [Sewage Sludge-NM: Smith et al.] "Breeding ewes in drylot were fed pelleted complete diets with 3% cottonseed meal (CSM) or 7% dried, gamma-irradiated sewage solids (DGSS) for 4 yr. Cytochrome P-450 content and enzyme activities for xenobiotics biotransformations were assayed in livers after 3 yr and in livers, kidneys and ileal tissue after 4 yr. Dietary DGSS caused no increase in P-450 and few changes in activities of oxidative, hydrolative, and conjugative biotransformational enzymes. Consumption of DGSS for 4 yr caused slight enlargement of spleens (1.1-fold) and ovaries (1.3-fold, $P<0.10$), but no change in size of livers, kidneys, hearts, adrenals and thyroids ($P>0.10$), nor liver vitamin A levels ($P>0.10$). Of 22 refractory lipophilic residues assayed in abdominal adipose tissue, few were detected and of those detected DGSS caused none to exceed normal levels. Dietary DGSS increased ($P<0.01$) Fe in livers 1.5-fold and in spleens 5.6-fold, and increased Cu in livers 1.3-fold ($P<0.01$) and in kidneys 1.2-fold. Dietary DGSS increased Cd levels in livers but not in kidneys or spleens ($P>0.10$); yet all Cd levels were within ranges for livestock fed conventional feed. Dietary DGSS caused no increase ($P>0.10$) in levels of Ag, Ca, Cr, Hg, K, Mg, Mn, Na, Ni, P, Pb, or Zn in livers, kidneys or spleens. There were no histopathological lesions of toxicosis except mild hemosiderosis of spleens. Consumption of a diet with 7% DGSS throughout 4 yr caused no hazardous accumulation of toxic elements and little, if any, evidence of toxicity."

Undigested sewage solids (primary and activated) from Las Cruces, NM. Dried and irradiated. Contained: 0.58% Fe; 606 ppm Zn; 405 ppm Cu; 361 ppm Cr; 150 ppm Pb; 99 ppm Pb; 11 ppm Ni; <5 ppm Hg; <1 ppm Se. 41.5% ash. Liver Fe was increased, 849±387 (SD) vs. 1303±291 ppm DW. Liver Cu was raised: 597±308 vs. 761±259 ppmDW. Liver Cd [<0.03 vs. 1.47±0.30 ppmDW] was raised, but kidney was not [2.8±0.8 vs. 3.5±0.6 ppmDW]. Pb was unchanged and at very low levels in liver, kidney, and spleen (<0.10 ppm DW). p,p'DDE was increased in fat, but PCB and other chlorinated hydrocarbons were not increased. The animals were mature, fine-wool ewes of Rambouillet breeding. ✓RLC•Ω

Vimmerstedt, J.P. and T.N. Glover. 1984. Boron toxicity to sycamore on minesoil mixed with sewage sludge containing glass fibers. Soil Sci. Soc. Am. J. 48:389-393.

TABLE 5. Maximum tolerable levels of dietary minerals for domestic livestock in comparison with levels in forages.

Element	Plant Foliage[a]	Maximum Levels Chronically Tolerated[b]					Soil-Plant Barrier[c]	Level in Normal Plant
		Cattle	Sheep	Swine	Chicken			
	--mg/kg dry foliage--	----------mg/kg dry diet--------						
As, inorg.	yes	0.01-1	3-10	50.	50.	50.	50.	
B	yes	7-75	75	150.	(150.)	(150.)	(150.)	
Cd[c]	Fails	0.1-1	5-700	0.5	0.5	0.5	0.5	
Cr^{3+}	yes	0.1-1	20	(3000.)	(3000.)	(3000.)	3000.	
Co	Fail?	0.01-0.3	25-100	10.	10.	10.	10.	
Cu	yes	3-20	25-40	100.	25.	250.	300.	
F	yes?	1-5	-	40.	60.	150.	200.	
Fe	yes	30-300	-	1000.	500.	3000.	1000.	
Mn	?	15-150	400-2000	1000.	1000.	400.	2000.	
Mo	Fails	0.1-3.0	100	10.	10.	20.	100.	
Ni	yes	0.1-5	50-100	50.	(50.)	(100.)	(300.)	
Pb[c]	yes	2-5	-	30.	30.	30.	30.	
Se	Fails	0.1-2	100	(2.)	(2.)	2.	2.	
V	yes?	0.1-1	10	50.	50.	(10.)	10.	
Zn	yes	15-150	500-1500	500.	300.	1000.	1000.	

a/ Based on literature summarized in Chaney et al. (1982).

b/ Based on NRC (1980). Continuous long-term feeding of minerals at the maximum tolerable levels may cause adverse effects. Levels in parentheses were estimated (by NRC) by extrapolating between animal species.

c/ Maximum levels tolerated were based on Cd or Pb in liver, kidney, and bone in foods for humans rather than simple tolerance by the animals.

From: Chaney and Ryan, 1993.

Boron Phytotoxicity: In contrast with municipal sewage sludge, MSW-compost contains substantial levels of soluble boron (B). B toxicity from sewage sludge application was reported only for an unusual case of a sensitive tree species growing in soils amended with a sludge containing lots of glass fibers (Vimmerstedt and Glover, 1984; see also Neary et al., 1975, regarding high B levels in phosphate-free detergents). The glass fibers contained borosilicate and release of B caused phytotoxicity. Research has shown that much of the soluble B in MSW-compost comes from glues (Volk, 1976). It has long been known that plant samples placed in paper bags can become contaminated from B from glue used to

hold the bag together. El Bassam and Thorman (1979) and Gray and Biddlestone (1980) noted that the B level in MSW-composts was quite variable as might be expected if composts are not well mixed.

In general, B phytotoxicity has occurred when high application rates were used, and B-sensitive crops were grown. However, when MSW-compost is used at fertilizer rates in normal fields, the B might be important as a fertilizer rather than as a potential phytotoxicity problem.

Boric acid and most borates are quite water soluble, although B can be adsorbed on clays and by organic matter. Low soil pH facilitates B uptake by plants because the H_3BO_3 molecule (predominant form at lower soil pH) is absorbed by roots rather than anionic borates (Oertli and Grgurevic, 1975). Although most B toxicity has been reported on alkaline soils, this is due to the lack of leaching for most of these soils. Excess applications of soluble B are much more phytotoxic in acidic soils, and liming can correct B phytotoxicity. The usual liming action of compost should help prevent this problem.

There are large differences among crop species in tolerance of excessive soil B. Some crops are very sensitive, and these are the species which have suffered phytotoxicity from compost-applied B (bean, wheat, and mum). Francois has summarized the significant differences among several groups of crops (Francois and Clark, 1979; Gupta, 1979; Francois, 1986). Ornamental horticultural species have been examined to some extent (information on individual species can be found by literature searching), but many horticultural crops have not been studied. This is one research need related to practical microelement phytotoxicity from compost.

Perhaps the first report on B toxicity from MSW-compost is that of Purves (1972) who noted B phytotoxicity to beans on field plots which received high rates of MSW-compost. The full description of the compost experiment is reported in Purves and Mackenzie (1973), and a careful examination to prove B phytotoxicity was reported by Purves and Mackenzie (1974). Bean (but not potato or other species examined) suffered severe yield reduction at high compost rates; this yield reduction was proportional to rate of compost application. Bean is known to be especially sensitive to B phytotoxicity. Gray and Biddlestone (1980) also found B phytotoxicity in sensitive species grown in field plots with high rates of MSW-compost.

Gogue and Sanderson (1975) reported B phytotoxicity to chrysanthemums in potting media containing MSW-compost. Foliar analysis clearly supported the conclusion that B was toxic and that Mn, Cu, Zn, and other elements were not at toxic levels. They conducted a calibration experiment to determine the sensitivity of chrysanthemums (Gogue and Sanderson, 1973), and the levels found in the mums grown on the test media were in the phytotoxic range. In their research, they adjusted the pH of the media to 6 using sulfur, rather than allowing the MSW-compost to raise the pH of the media. This probably contributed to the severity of B phytotoxicity observed. Some other horticultural species also suffered B phytotoxicity in compost-containing media (Gilliam and Watson, 1981). Sanderson (1980) reviewed B toxicity in compost amended potting media. In contrast to MSW-compost, sewage sludge composts with wood chips have not been found to cause B phytotoxicity (Chaney, Munns, and Cathey, 1980). Only a few acid-loving

species require acidification of media to do well on neutral compost-amended media.

Interestingly, because the B which causes phytotoxicity is water soluble, the B phytotoxicity problem from MSW-compost is short-lived. Purves and Mackenzie (1973) noted that pre-leaching MSW-compost prevented B phytotoxicity. Other studies noted that the B-phytotoxicity occurred only during the year of application, and that soluble B was leached out of the root zone over winter (Volk, 1976) or by leaching potting media with normal horticultural watering practices. Sanderson (1980) noted that perlite also adds B to potting media, and that use of both may cause B toxicity when either perlite or MSW-compost alone might not have done so. Lumis and Johnson (1982) studied leaching of B in relation to toxicity of salts and B to *Forsythia* and *Thuja*. They reported that a simple leaching treatment removed excess soluble salts, but was unable to remove enough B to prevent phytotoxicity (the compost they studied contained 225 mg B/kg, higher than most reports). Nogales et al. (1987) also found compost-applied B leached quickly such that crop B was reduced in each successive ryegrass crop.

B phytotoxicity is significantly more severe when plants are N-deficient (Gogue and Sanderson, 1973; Nogales et al., 1987; Gupta et al., 1973). This makes the B in MSW-compost which is not properly cured (to avoid N immobilization) potentially more phytotoxic than in well cured composts. Further, B flows with the transpiration stream and accumulates in older leaves. In environments with low humidity, more transpiration occurs (e.g., greenhouses), and B toxicity is more severe. B and salt toxicity are easily confused; both are first observed in leaf tips or margins of older leaves. Diagnosis of B phytotoxicity requires a knowledge of relative plant tolerance of B, or analysis of the leaves bearing symptoms.

Thus, in general use, compost application at a reasonable fertilizer rate would simply add enough B to serve as a fertilizer for B-deficiency susceptible crops such as alfalfa or cole crops. However, use of MSW-compost at high rates in soils or potting media could cause phytotoxicity if high soluble B were present. The B phytotoxicity would not be persistent because soluble B would leach from the root zone with normal rainfall or irrigation. Compost-applied B would be more phytotoxic in N-deficient soils, which might result from application of improperly cured compost. Water soluble B should be one chemical which is regularly monitored in MSW-composts so that the need for warning about rates of application and use with sensitive crops can be identified. Deliberate use of MSW-compost as a B fertilizer for high B-requiring crops such as the cole crops (cabbage family) might become a regular agronomic practice. Sources of soluble B in modern MSW-compost should be evaluated, and alternative to B use identified.

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Vol. 19, no. 3, July–September 1990, Copyright © 1990, ASA, CSSA, SSSA
677 South Segoe Road, Madison, WI 53711 USA

Plant Uptake of Pentachlorophenol from Sludge-Amended Soils

Cheryl A. Bellin and George A. O'Connor

Ryan, J.A., et al. 1988. Plant Uptake of Non-Ionic Organic Chemicals from Soils. Chemosphere, Vol. 17, No. 12, pp. 2299-2323. Pergamon Press.

Available for inspection at the EPA Docket Center, please contact the Office of Water Docket for further information, 202-566-2426.